

Physico-mechanical Properties of Ecofriendly Bricks using Recycled Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) Wastes as Binders



Y. O. Busari^{1,2*}, R. O. Idowu¹, A. Reghioua³, K. S. Ajao¹, S. Sikiru⁴, Y.L. Shuaib-Babata¹, I.S. Ibrahim¹, N. M. Abbas², J.O. Adegbola¹ and T. Yahaya¹

¹Department of Materials & Metallurgical Engineering, University of Ilorin, PMB 1515, Nigeria.

²Smart Manufacturing Research Institute & School of Mechanical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Malaysia.

³Laboratory of Applied Chemistry and Environment, Faculty Technology, University of El-Oued, 39000 El Oued, Algeria.

⁴School of Physics and Materials Studies, Faculty of Applied Sciences, Universiti Teknologi Mara, 40450, Shah Alam, Selangor, Malaysia.



ABSTRACT: Soil-cement bricks in Nigeria are preferred for building due to environmental, technical, and economic benefits, while reinforced polymer composites are increasingly popular for their lightweight construction and biodegradability. However, the composition of Portland cement still generates environmental impacts due to CO₂ emissions. Thus, this study aimed to produce eco-friendly bricks through a mixture of river sand, recycled polyethene terephthalate (PET) and low-density polyethene (LDPE) wastes that were shredded and melted as binders for the aggregates to create bricks in various ratios (1:1, 1:2, 1:3) and hybrid of PET and LDPE ratio (1:1:2 and 1:1:4). The bricks were then air-dried and cured to solidify and bricks were evaluated using compressive strength, flexural strength, water absorption, and density measurements. The river sand sample chemical analysis revealed the sand belong to Alumino-Silicate as values for percentage clay contents. The water absorption for recycled binder was within the permissible limit between 0.4%-1.5%. Similarly, the use of both recycles PET and LDPE as a binder with river sand in ratios such as (1:1:2) enhanced the stiffness strength with mean values of 3.6 N/mm² and 13.4%, while recycled PET as the binder in a ratio (1:3) only significantly improves compressive strength with mean values of 13.6 N/mm² demonstrating adequate bonding and mechanical robustness.

KEYWORDS: Portland cement, PET, LDPE, Brick, CO₂ Emissions

I. INTRODUCTION

Due to climate change and global warming, construction industry sustainability is essential for every nation. Bricks are one of the mostly used materials in building with standard proportions of clay, sand and a binder (Murmur and Patel, 2018). Cement which contains low tricalcium aluminate, is a preferred binder in bricks due to its ability to harden and adhere to sand and aggregates, improving yield strength (Alkaysi, 2016). Studies have shown that Portland type of cement has acceptable strength and durability is commonly used in Nigeria (Wille and Boisvert-cotulio, 2015; Gao et al., 2016). However, its production poses great environmental challenges. Life cycle assessment is crucial for assessing environmental impacts in the construction industry. Current impact categories include climate change, human toxicity and freshwater ecotoxicity.

The importance of plastics and polymers of high molecular mass varies in human life, ranging from packaging, electronics, healthcare and construction, to mention a few. Over 1.3 billion metric tons of plastics are produced annually

all over the world (Yadav *et al.*, 2020). About 40% of all plastic manufactured for packaging purposes is single used, which constitutes a nuisance to the environment from the terrestrial to marine ecosystems while only about 9% of plastic generated is recycled (Geyer *et al.*, 2017; T. Ghosh et al., 2023). The sustainable development of the metropolitan area requires the authorities to find a way of removing plastic from their locality. Therefore, there is an urgent need for innovative ways to reduce plastic waste and its impact on the environment. According to the Global Plastic Action Partnership report in 2023, Nigeria ranks ninth globally among countries with the highest contributions to plastic pollution, with about 2.5 million tonnes of plastic waste annually and only 20% of this waste is properly managed (SCA, 2023). Poor waste management, inadequate collection and recycling infrastructure and limited awareness of the adverse effects of plastic waste exacerbate the problem. The University of Ilorin in Kwara State alone generates tonnes of plastic waste annually, highlighting the need for solutions that can be applied locally to align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13

*Corresponding author: yusufbusari@uitm.edu.my

(Climate Action), by promoting resource efficiency and reducing plastic pollution.

Recycled plastics present innovative applications in construction materials, significantly contributing to sustainability in modern architecture. The integration of hard-to-recycle plastic waste into building materials has been explored, showcasing its potential to reduce environmental impact and promote a circular economy (Bharadwaj *et al.*, 2024; Cudzik and Kropisz, 2024). Plastic bricks made from recycled plastics, demonstrate structural integrity and cost-effectiveness, addressing both waste management and resource consumption challenges. Additionally, various forms of recycled plastics can replace traditional aggregates in cementitious composites, enhancing durability and thermal properties (Ahmed and Ali, 2023; Debele *et al.*, 2024). Notably, the production of plastic bricks using PET and sand blends has shown promising results in compressive strength and insulation, making them suitable for diverse applications (Amjad and Diaz-Elsayed, 2024; Hamada *et al.*, 2024; Sidar *et al.*, 2024).

Sustainable and circular economic models have focused development of light materials, waste reuse, and alternative fuel sources (Ramos *et al.*, 2020). Low-density polyethylene (LDPE) has proven difficult to manage due to its maximum service temperature, stiffness and low strength with low resistance to ultraviolet light (Hopewell, Dvorak and Kosior, 2009; Ragaert *et al.*, 2017). Polyethylene Terephthalate (PET) is mostly used for food packaging material since it is light, soft, low-cost in production and easy to recycle. Recycling PET and LDPE offers environmental benefits that reduce plastic waste in landfills and promote sustainable resource management (Adiyanto *et al.*, 2023). Interlocking paving bricks made from LDPE-sand composites exhibit superior mechanical performance compared to PET-sand composites, with the LDPE-sand mix ratio of 3:1 achieving a compressive strength of 31.11 N/mm² and minimal water absorption, indicating better compatibility and durability (Nnorom *et al.*, 2023). This process does not involve heavy combustion, preventing harmful emissions. Also, the modified bitumen with PET, LDPE or DPET enhances compressive strength and reduces costs, making the process economically viable (Hameed *et al.*, 2023; Singh *et al.*, 2023). The effectiveness of cement mortar that uses recycled PET with 3mm- 9mm long PET particles size and construction debris waste aggregates with sand for brick production is more efficient in energy conservation by substituting natural river sand and reduce cement usage with the desired mechanical strength of 2MPa while maintaining the original bulk density and water-related characteristics mechanical and physical properties that meet standard requirements effectively (Peisino

et al., 2024). Ecofriendly bricks that utilizes recycled PET and low-density polyethylene (LDPE) wastes as binders exhibit promising physico-mechanical properties, making them viable alternatives to conventional construction materials (Gounden *et al.*, 2024). Therefore, this study provides a sustainable pathway to recycle and repurpose PET and LDPE wastes, addressing global concerns regarding plastic pollution and its environmental impacts. It establishes a novel application for these materials in the construction sector, diverting them from landfills and incineration. Bricks have different formulations used in various regions, and the material combinations differ based on the ratio of polymer type, particle sizes and curing time with other raw material combinations; all those benefits come from its unique compactness and constituents. Therefore, the present study intends to analyse the influence of recycled PET and LDPE from disposable sachet water on the river sand used for making bricks as binders. The physio-mechanical properties of the produced brick composites were investigated.

II. MATERIALS AND METHODS

A. Materials

The waste PET bottle and LDPE sachet nylons were sourced from the accumulated waste-bin in a private hostel at the University of Ilorin. The river sand was dug from the University of Ilorin Dam, which lies between latitude 8.4799°N and longitude 4.5418°E, Ilorin, Nigeria and washed with water, cleaned, sun-dried and shredded for easy melting. The elemental chemical compositions of the river sand samples were determined using X-ray fluorescence (XRF) Analysis (Epsilon 5, PANalytical B.V, Netherlands) at the National Geoscience Research Laboratories Centre, Kaduna State, Nigeria, by the procedures used by earlier researchers (Mshelia *et al.*, 2016; Oke and Omidiji, 2016). The dry sand was sieved using a 600-micron sieve to get a fine, uniform particle size to increase the compactness as seen in Figure 1. PET and LDPE were chosen due to their characteristics of toughness, solvent-resistant, the barrier to gas and moisture, softens at 80°C and forming soft, flexible, waxy surfaces, and translucent and softening at 70°C, respectively (Singh *et al.*, 2023).



Figure 1: (a) Recycled-PET; (b) Recycled-LDPE; (c) Unilorin River sand

B. Brick production

The mould was fabricated with mild steel for a smooth finish relative to the interlocking brick size of (230 x 115 x 76) mm with a plunger. Figure 2 presents the process of casting plastic sand bricks starts with the batching, which involves weighing the sand and the PET/ LDPE samples in various weight proportions as stipulated in Figure 2: Schematic process of production

Table 1. All sample compositions were name-coded for ease of investigation. The samples with PET and sand only (P-series), LDPE and sand only (L-series) and the mixture of PET, LDPE and sand are labelled (H-series) samples. LDPE is noted for its low-temperature flexibility, toughness, and corrosion resistance. It is unsuited for applications requiring stiffness, high-temperature resistance and structural strength. Therefore, a blend with PET is needed. The shredded PET/LDPE wastes were heated above their softening temperature in the aluminium pot to 110°C before manually adding the river sand to the melted plastic wastes with continuous stirring for almost 5 minutes. The mixture was homogenised and poured into an iron mould lubricated with engine oil to remove the moulds quickly. The cast brick was allowed to cool at ambient temperature. The mould edge was hit continuously for a few minutes to ensure proper compaction. Before testing, the samples were de-moulded and cured for seven (7) days for other specimen and twenty-eight (28) days at room temperature for mechanical testing.

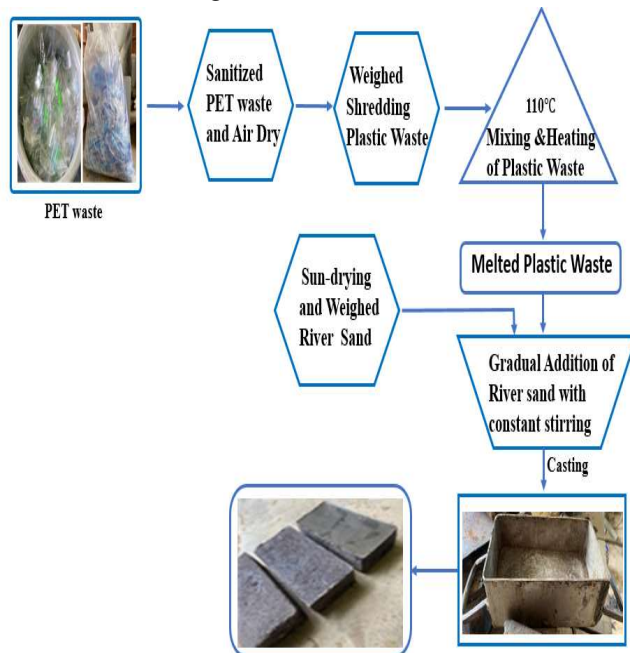


Figure 2: Schematic process of production

Table 1: Brick material composition

Sample ID	Recycled PET (wt.%)	Recycled LDPE (wt.%)	River sand (wt.%)
L50	0	50	50
L33	0	33	67
L25	0	25	75
P50	50	0	50
P33	33	0	67
P25	25	0	75
H50	25	25	50
H33	16.5	16.5	67

C. Characterization of the Eco-friendly Bricks

Visual inspection was done after using a flat-bottomed container with sufficient distilled immersion depth is 25mm. The brick was immersed in distilled water for 28 days before being removed for the efflorescence test. Furthermore, the morphology of the bricks was examined using an optical microscope (XL 30, Philips Eindhoven, Netherlands). The analysis was conducted at a magnification of 200x. The brick sample was prepared by cutting it to a smaller size for easy mounting on the optical microscopy equipment, after which it was smoothed to ensure a smooth and balanced surface.

(i) Physical Property Test:

The bulk density (ρ) (g/cm³) describes the mass of the brick per unit volume by quantifying a closely packed brick specimen. The dehydrated brick specimen with the dry mass is weighed and divided by the container volume, as depicted in Equation (1.0). The water absorption test uses ASTM standard C67/ C67-20 (ASTM: C67/C67M –20, 2020). The bricks were weighed in arid conditions and then immersed in fresh water for about 24 hours in a container. The wet brick was removed and weighed after being wiped with a cloth. This process was repeated for seven days, 14 days, and 21 days, respectively. The alteration in weight was documented and employed to compute the percentage water absorption with Equation (2.0).

$$\text{Density } (\rho) \left(\frac{g}{cm^3} \right) = \frac{\text{Dry mass } (g)}{\text{Volume } (cm^3)} \quad (1)$$

$$\text{Water absorption } (\%) = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} * 100 \quad (2)$$

(ii) Mechanical test:

The mechanical test was conducted for its compressive strength test using ASTM C67. The specimens are prepared with dimensions suitable for the testing apparatus, ensuring consistency in size and shape across samples. A hydraulic system is used to manually apply compressive axial load at a

convenient rate until failure occurs as depicted in **Error! Reference source not found.** (a&b). The value obtained was taken into account when calculating the breaking point, and the compressive strength of the brick was calculated. The compressive strength test of each brick sample was determined using the Equation (3.0).

$$\begin{aligned} & \text{Compressive strength (N/mm}^2\text{)} \\ &= \frac{\text{Maximum load applied (N)}}{\text{Specimen Area(mm}^2\text{)}} \end{aligned} \quad (3)$$

The flexural test was conducted to assess the produced eco-friendly brick strength, stiffness, and deformation characteristics by applying a load to a brick depicted in c & d. The Universal Testing Machine (UTM) (Model FT300CT, Testometric Company Ltd, United Kingdom) test was conducted with a three-point bending setup with bricks positioned horizontally on supports with three compositions per sample. The load was applied at the centre until the brick was fractured, and the calculation of flexural strength in Equation (4.0) after the maximum load was recorded for each composition.

$$\begin{aligned} \text{Flexural strength (N/mm}^2\text{)} &= \frac{3FL}{2bd^2} \\ &= \frac{3F(\frac{L}{2-x})}{bd^2} \end{aligned} \quad (4)$$

F represents the maximum applied load, L represents the distance between the supports, b and d represents the width and thickness of the specimen, and x represents the distance from the plane of failure to midspan.



Figure 3: (a) & (c) Compressive strength and flexural strength test machines, (b) & (d) Performance of compression and flexural load-carrying capacity of bricks after failure.

III. RESULTS AND DISCUSSION

A. Chemical composition of the river sands

The analysis of Unilorin river sands reveals that silica (SiO₂) is the dominant composition, accounting for 58.621 wt.%; sands belong to the Alumina-Silicate sand group due to

their high silica content and other significant compounds as presented in Table 2(Radkovský *et al.*, 2022). These include alumina (Al₂O₃), iron (III) oxide (Fe₂O₃), potassium oxide (K₂O), and calcium oxide (CaO), which are of similar composition and essential for brick sand (Božič *et al.*, 2023). MgO was absent in river sands, although its absence may have a minimal impact on the sand strength. Understanding the chemical composition is crucial when selecting sand. High silica content enhances refractoriness and chemical inertness, preventing defects like blowholes and burning of sand particles (Shuaib-Babata and Abdulrahman, 2018). The enhancement of strength and packing density in bricks by silica-rich river sand can be attributed to its unique crystal structure(Imseeh *et al.*, 2023).

Table 2: Chemical Analysis of Unilorin River Sand

Constituent	Unilorin (wt.%)	Constituent	Unilorin (wt.%)
SiO ₂	58.621	CaO	2.562
V ₂ O ₅	0.108	MgO	0.000
Cr ₂ O ₃	0.030	K ₂ O	9.107
MnO	0.317	BaO	0.586
Fe ₂ O ₃	10.692	Al ₂ O ₃	14.074
Co ₃ O ₄	0.034	Ta ₂ O ₅	0.065
NiO	0.005	TiO ₂	1.503
CuO	0.085	ZnO	0.012
Nb ₂ O ₃	0.012	Ag ₂ O	0.055
MoO ₃	0.006	Cl	0.809
WO ₃	0.022	ZrO ₂	0.323
P ₂ O ₅	0.322	SnO ₂	0.154
SO ₃	0.497		

B. Morphological examination

The visual inspection of the produced eco-friendly brick shows no efflorescence when the bricks come in contact with water after 28 days of dryness and no grey or white patches appear on the brick surface as presented Figure 4 with very low drying shrinkage. One of the key characteristics of LDPE is the presence of significant branching along its polymer chains (Shinohara *et al.*, 2019). These side branches prevent the chains from packing closely together, leading to a less compacted LDPE-based L33, L25 and H33 with more sand portions. The PET based samples P50, P33, P25 show more rigid bricks which can be attributed to the molecular structure in PET that leads to tighter packing and a higher degree of crystallinity. Furthermore, Figure 5 shows the sand distribution in the matrix composite systems that were examined with the optical microscope. The addition of higher percentage of sand to the PET melt effectively fills the gaps between the sand and plastic particles as seen in P25, thereby reducing porosity and yielding a more uniform and solid structure within the same ratio as compared to the LDPE samples L33, L25 and H33 respectively. This suggests that river sand occupies the spaces among the particles, mitigating the occurrence of air pockets or voids. This decrease in voids and porosity significantly enhances the structural integrity of the brick.

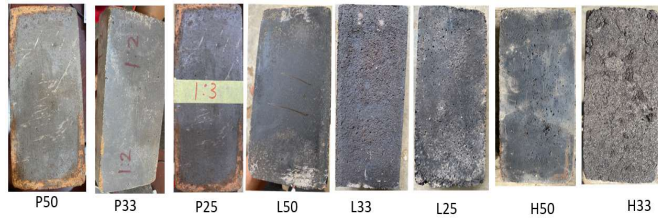


Figure 3: Produced eco-friendly brick

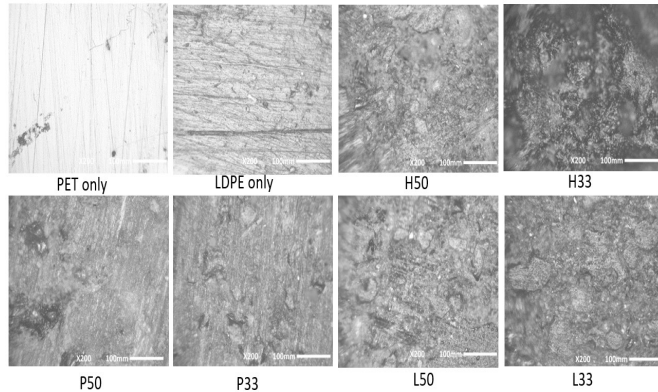


Figure 4: Brick samples optical microscopy images

C. Bulk Density

The results showed that the density increased as the quantity of sand increased in each of the aggregate mixtures, as well as the difference in density between LDPE based brick and PET based brick can be attributed to their inherent molecular structures. According to the graph in Figure 5, the addition of more sand resulted in an appreciable increase in bulk density of P25, L25 and H33, which can be ascribed to the greater density of PET plastics as seen in the work of (Peisino *et al.*, 2024). The difference in performance is caused by the raw material bulk densities and the aggregate percentage since a uniform particle size of sand is used to impact the packing density of the samples. The performance mixture of LDPE and PET densities could be attributed to the complementary role of the linear arrangement of PET chains that allows for more closely pack more closely together in a crystalline structure, leading to a slightly higher density of H33 (1.54g/cm³) compare only LDPE mixture of L33 (1.52g/cm³). Furthermore, the possibility of byproduct rich in SiO₂ due to the production process, has been shown to improve compressive strength. This is attributed to the pozzolanic reaction, which enhances the binding properties of the material, leading to a denser and stronger brick structure(Ait Salem, Benchouk and Belayachi, 2023). Recycling plastic waste as an additive like cement, can enhance brick strength and reduce environmental pollution. However, a balance of density and strength is crucial for appropriate structural qualities(Gounden *et al.*, 2024).

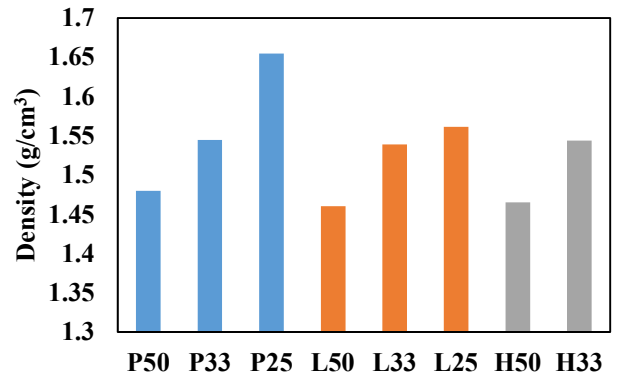


Figure 5: Density of the brick samples

D. Water absorption result

The percentage increase in the ratio of river sand resulted in eco-friendly bricks reflects substantial increase in the rate of water absorption primarily due to the hydrophobic nature of PET and LDPE, which prevents water from penetrating the brick structure (Sidar *et al.*, 2024) as seen in Figure 6. The P50, L50 and H50 samples with lower water absorption due to its maximum recycled plastic proportion. This could be attributed to closure of capillary action driving water into the open pores in the higher proportion of PET and LDPE, allowing moisture to move slowly through the material. Moreover, the compatibility of LDPE and PET with sand particles enhances the brick's structural integrity, further reducing water absorption (Nnorom *et al.*, 2023). The mixture ratios and materials' water absorption behaviour have influenced polymer mixtures in interlocking applications (Bamigboye *et al.*, 2019; Bamigboye *et al.*, 2021).

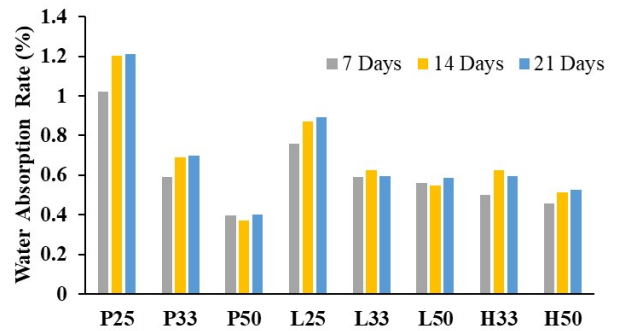


Figure 6: Rate of water absorption of samples

E. Compressive and Flexural Strength

The compressive and flexural strengths are crucial to determine the suitability of bricks for various construction applications. Figure 7 depicts the bricks made from PET with equal weight percentages (P50) exhibited the maximum compressive strength, with an average strength of 13.8 N/mm². This demonstrates that PET as a binder has a substantial impact on eco-brick strength. Nevertheless, as the sand content increased in the mixture, it resulted in a modest reduction with

a mean value of around 12.2 N/mm². Nevertheless, as the sand content increases in the mixture resulted in a modest mean values of around 12.2 N/mm². This phenomenon may be ascribed to the fact that PET improves cohesiveness, an excessive amount of sand might interfere with this cohesion, decreasing the total strength (Modi *et al.*, 2023). Compressive strength is one of the important properties for bricks, particularly for load-bearing structures, such as walls or foundations. The heightened porosity might result in reduced compressive strength due to an increased number of voids present in the material. Samples containing a mixture of recycled PET and LDPE (L25, L50, L33, H25, H50) showed compressive strengths ranging from 4.8 to 10.4 N/mm². This range indicates the use of recycled plastics as binders (both PET and LDPE) reduce porosity and improved compressive strengths depending on the ratios used. This is consistent with existing results from literature (Carbonell Muñoz, 2012; Wahid *et al.*, 2015; Tai *et al.*, 2020).

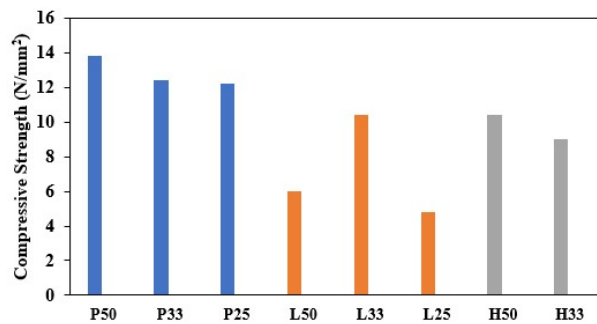


Figure 7: Compressive strength of the brick samples

Secondly, the measure of brick ability to withstand stress perpendicular to the brick's length is critical in the evaluation of the performance of bricks under lateral loads. The values of the samples in P50 and P33 are within the values in the literature using PET and little cement, which is about 2 N/mm² (Arulrajah *et al.*, 2020). Also, applying recycled LDPE with various proportions of sand shows more stiffness strength than the Recycle PET binders, ranging with mean values from 3.4 N/mm² to about 6 N/mm². According to the data presented in Figure 8, the failed sample are within the allowable modulus of rupture, and the flexural strength shows an almost two-fold increase when more sand particles are used in recycled PET and LDPE binders. The minimum net area compressive strength requirement for a brick wall as for non-load-bearing wall masonry is 3.45 N/mm² (Fatina Md Sali and Deraman, 2019) and ASTM C34 structural clay load-bearing tile is around 12.6N/mm². These findings show that substituting sand with plastic waste increases compressive and flexural strength. The influence of river sand with greater proportion of Silica (SiO₂) more than 45% has been found to maintain or even enhance compressive strength, indicating that silica

contributes positively to the mechanical properties of the composite material (Ghosh *et al.*, 2023).

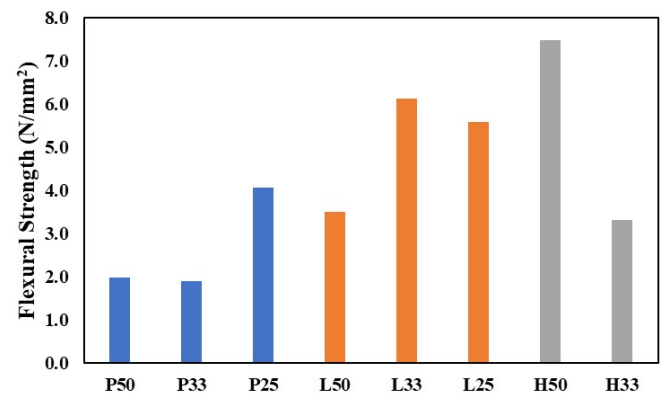


Figure 8: Flexural strength of the brick samples

IV. CONCLUSION

Sustainable technology models for construction materials are growing rapidly since there is rising need for lightweight, structural strength and durable eco-friendly bricks. The use of recycled PET and LDPE as binders helps reduce plastic pollution and promotes the circular economy by giving new life to otherwise biodegradable plastic waste. The following conclusion can be drawn:

- The physical characterization of the eco-brick samples revealed that the density and water absorption with increase in river sand. LDPE-based bricks have lower bulk densities when compared to PET-based bricks, and the hybrid material provided a middle ground that offers a balance property.
- The microscopic examination on the brick samples showed that the homogenous and largely dispersed evenly matrix
- Mechanical characterization showed that the samples with higher composition of PET and sand aggregates possessed better compressive strength. However, the flexural strength of the samples was merely influenced by the varying composition of both recycled plastics with the hybrid samples having higher strength value.

Further studies on the mechanical test for earlier curing time of 7, 14 and 21 days might be necessary from the economic standpoint of product to market timing. Other factors that can affect the long-term durability and weather resistance characteristics such as ultraviolet resistance, Thermogravimetric analysis to observe the mass loss with an increase in temperature at a given environment can be considered.

AUTHOR CONTRIBUTIONS

Conceptualization: **Y. O. Busari, R.O. Idowu, A. Reghioua**; Methodology, Laboratory: **I.S. Ibrahim, R.O. Idowu, J.O. Adegbola, K.S. Ajao**; Writing – Original draft: **T. Yahaya, Y. O. Busari**; Writing – review & editing: **S. Sikiru, N.M. Abbas, Y.L. Shuaib-babata**.

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